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(54) **ROBOTIC SYSTEM FOR RETRACTABLE TELEOPERATED ARM WITHIN ENCLOSED SHELL WITH CAPABILITY OF OPERATING WITHIN A CONFINED SPACE**

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(52) **U.S. Cl.** **700/245**; 700/245; 700/275; 318/568.11

(58) **Field of Search** 700/243, 245, 700/275, 247, 250; 137/13, 15; 318/568.11

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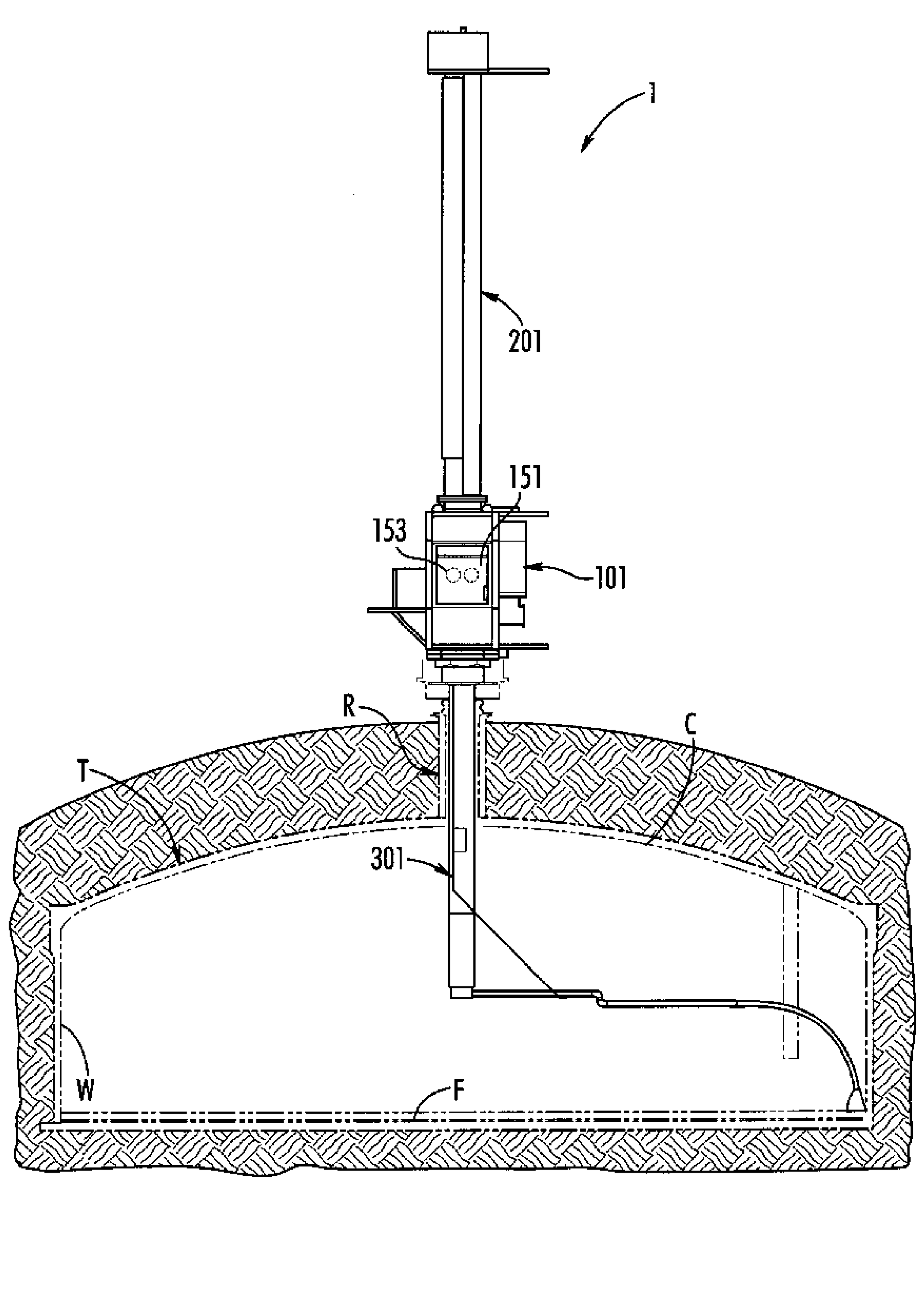
(57) **ABSTRACT**

An apparatus for performing a task in a confined space having an access port. The apparatus comprise: a confinement box securable to the access port of the confined space; a shell extending from the confinement box; a teleoperated arm movable between a retracted position, in which the teleoperated arm is disposed within the shell, and a deployed position, in which the teleoperated arm extends through the access port and into the confined space to perform the task; and a control system for commanding the teleoperated arm. The arm links and joint connectors of the teleoperated arm assembly are the conduits for the process

24 Claims, 12 Drawing Sheets



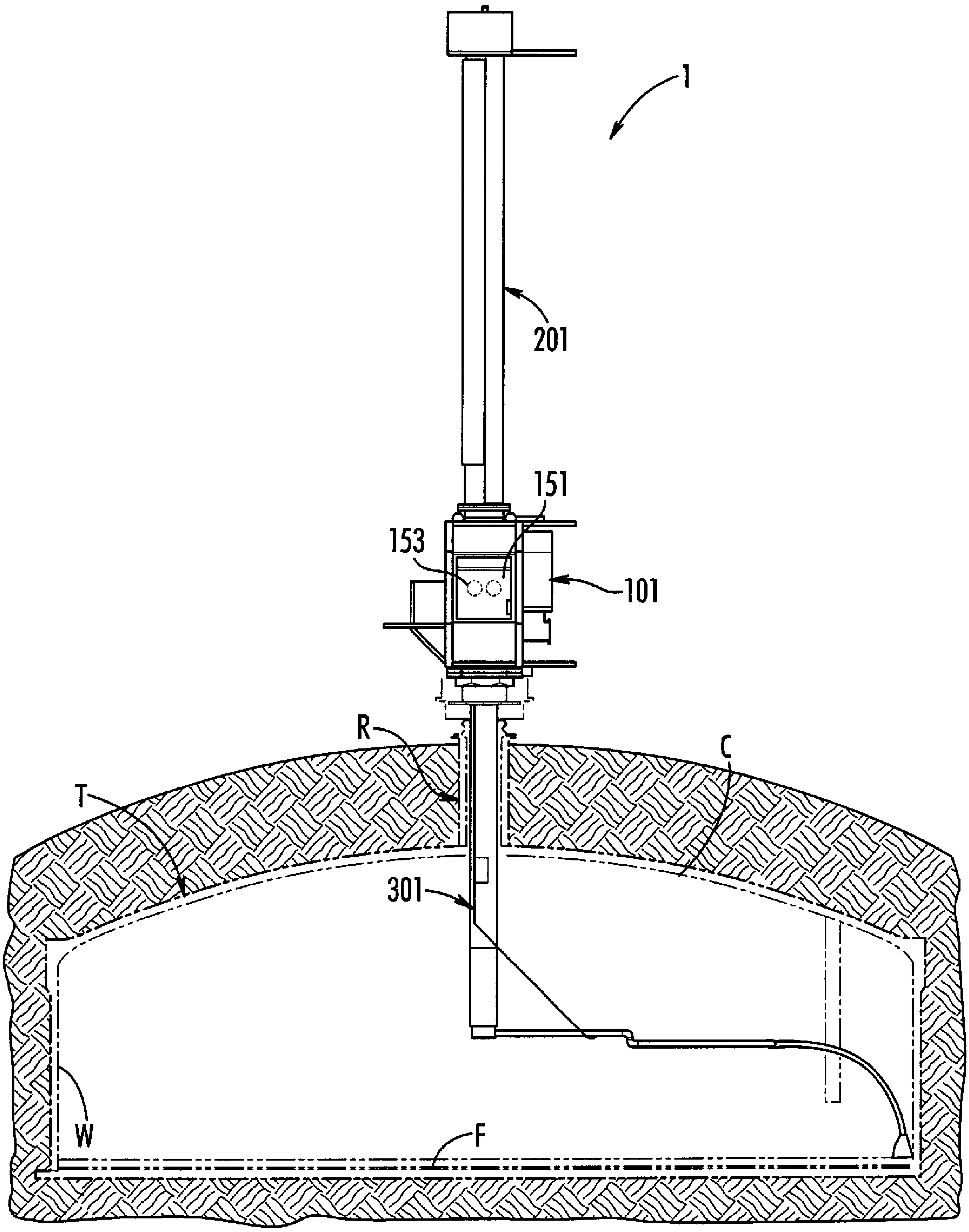


FIG. 1

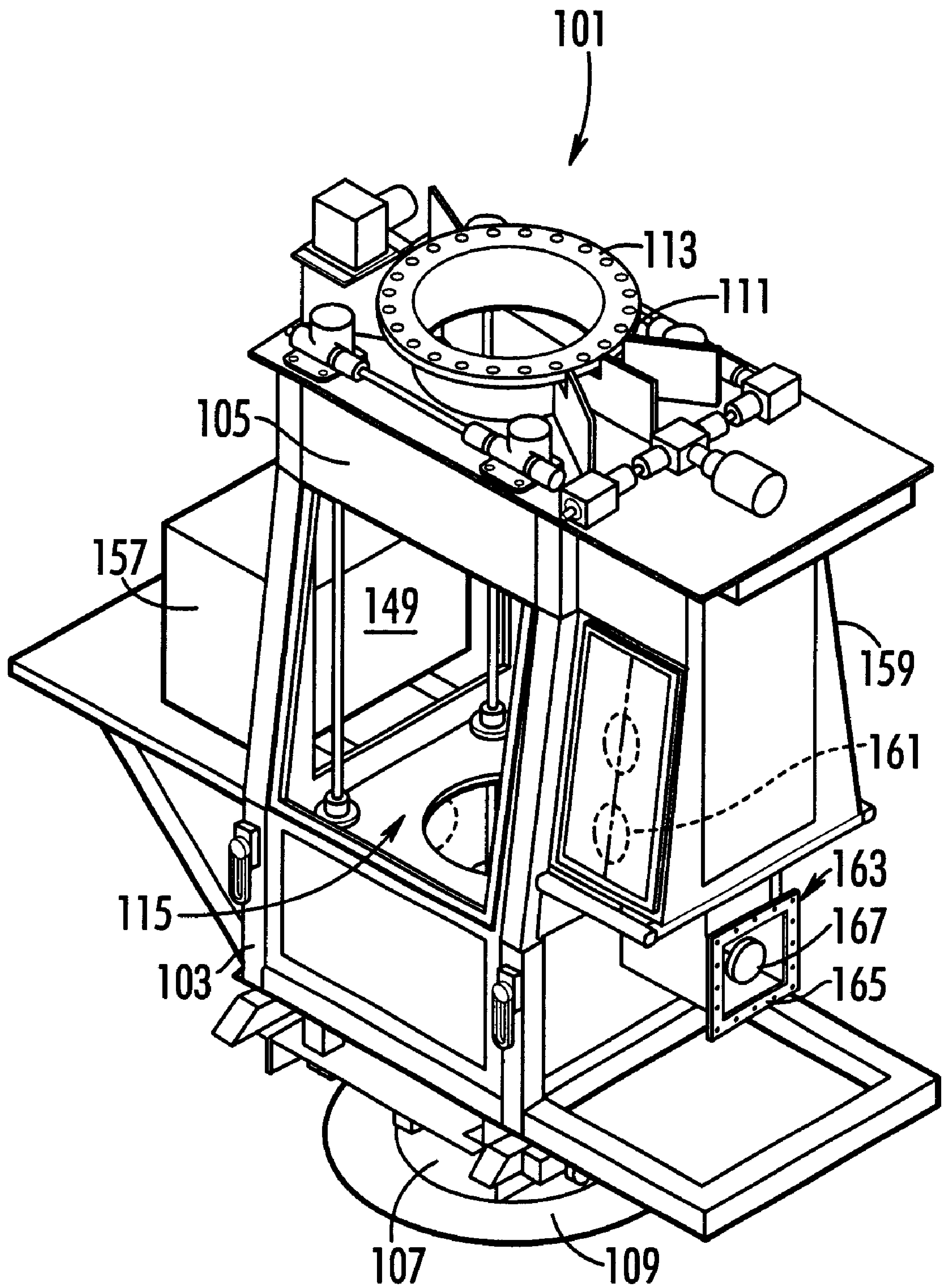


FIG. 2

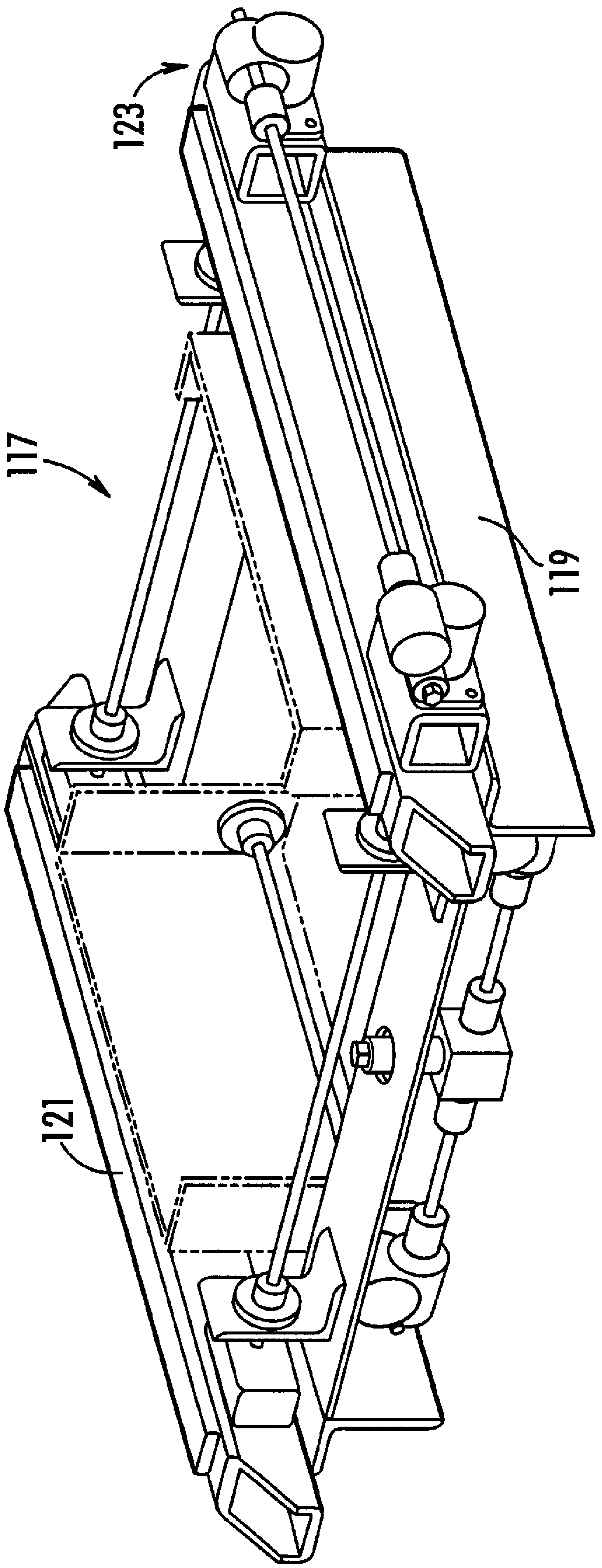


Fig. 3

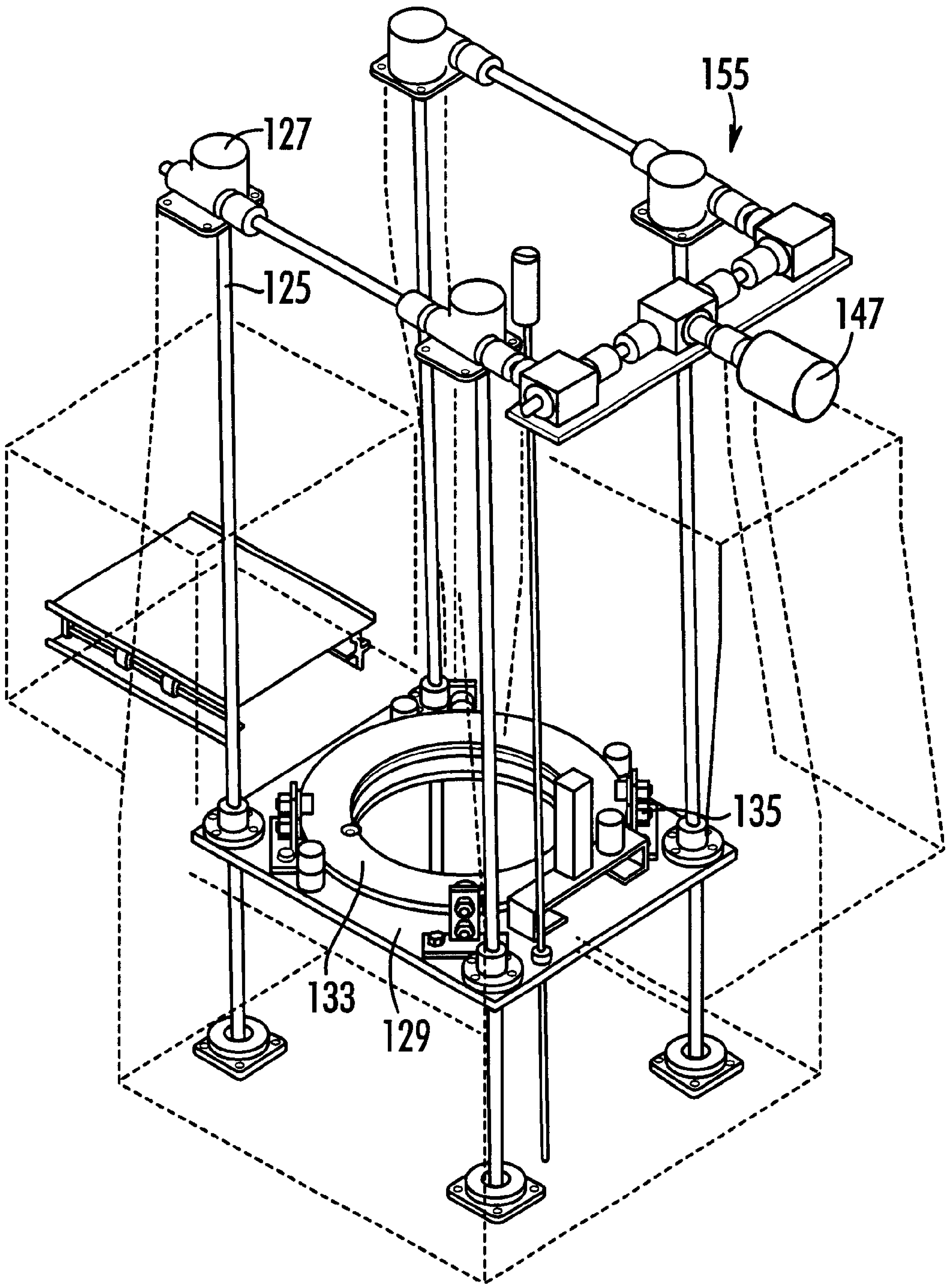


Fig. 4

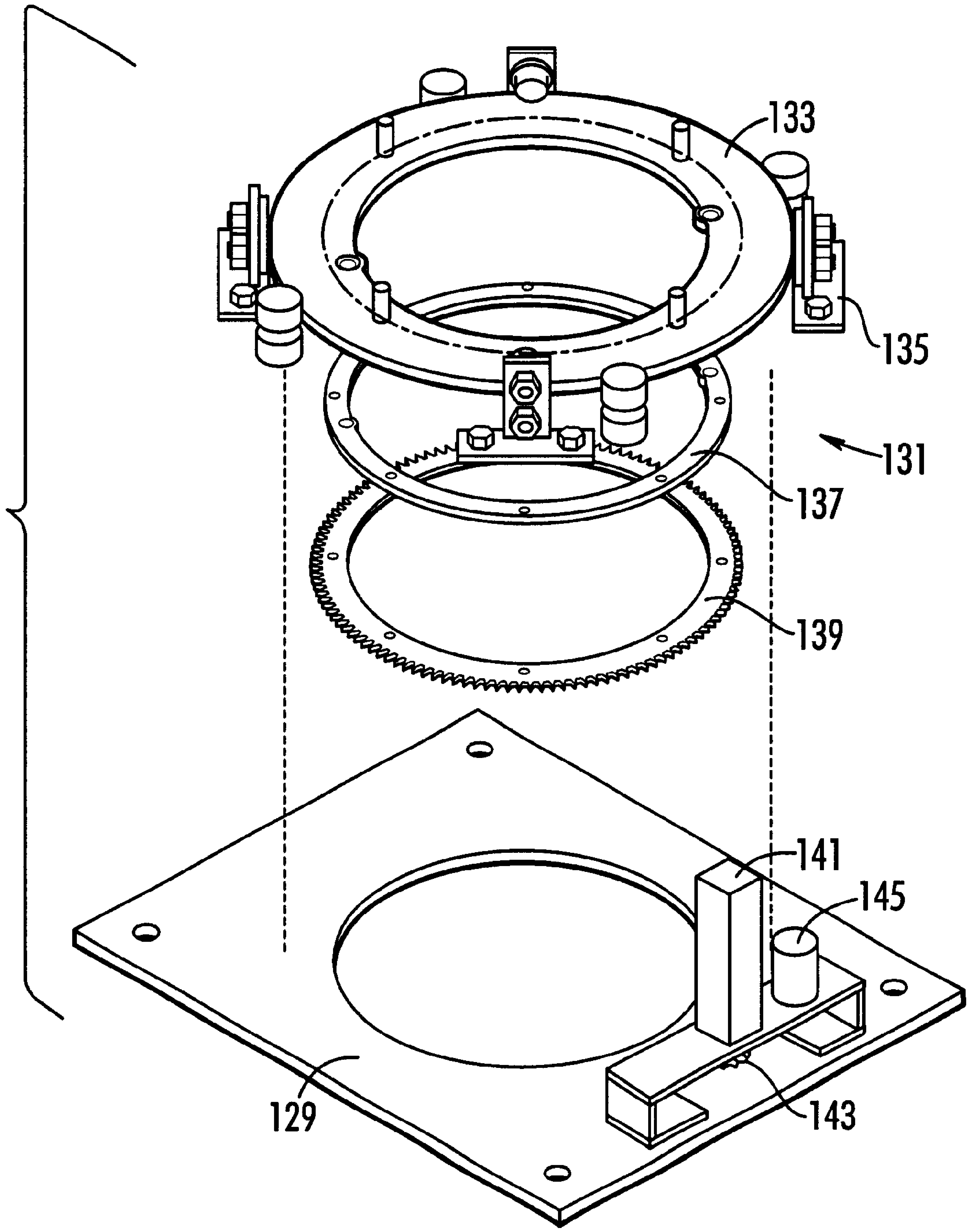


FIG. 5

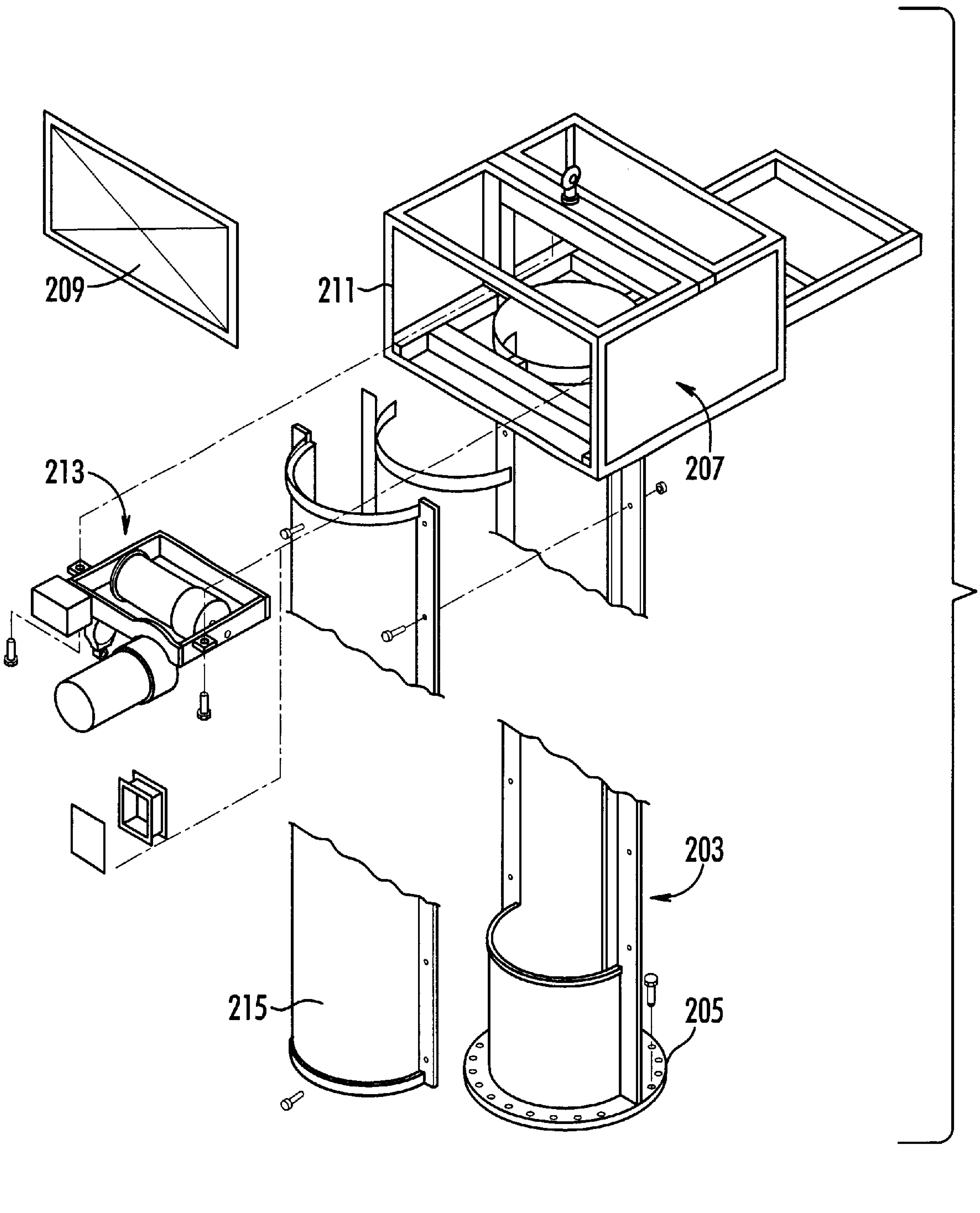


FIG.6

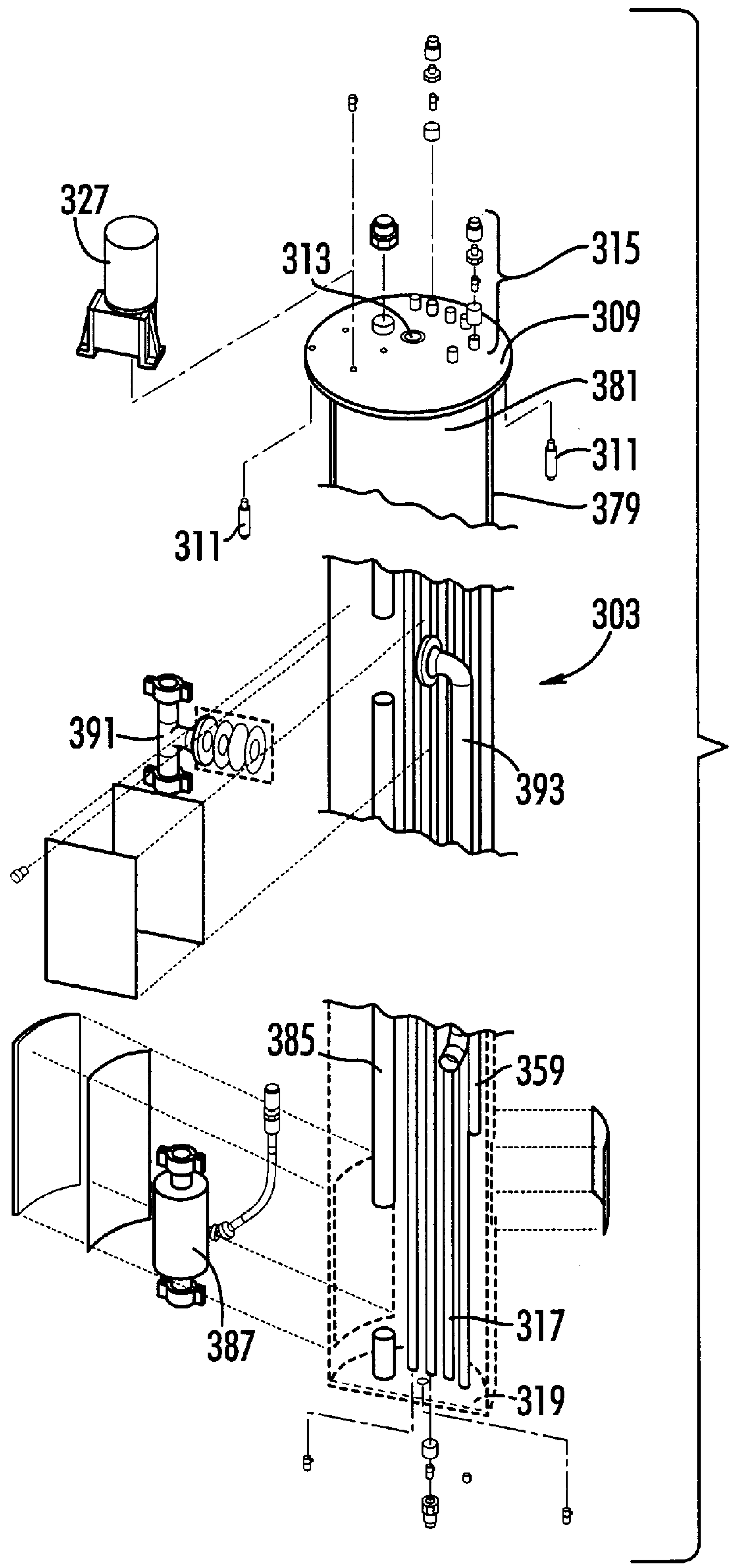


FIG. 7

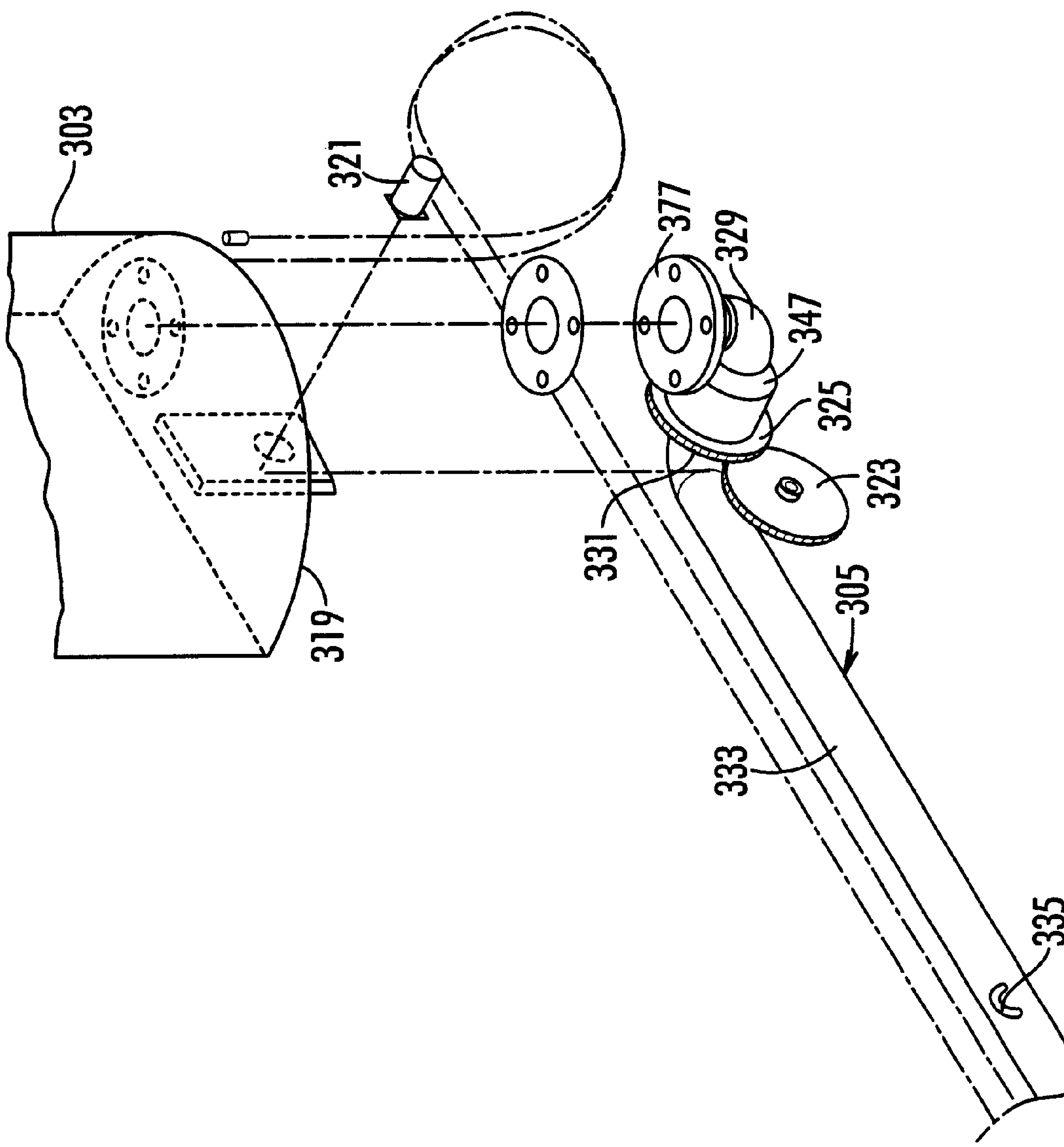


FIG. 8

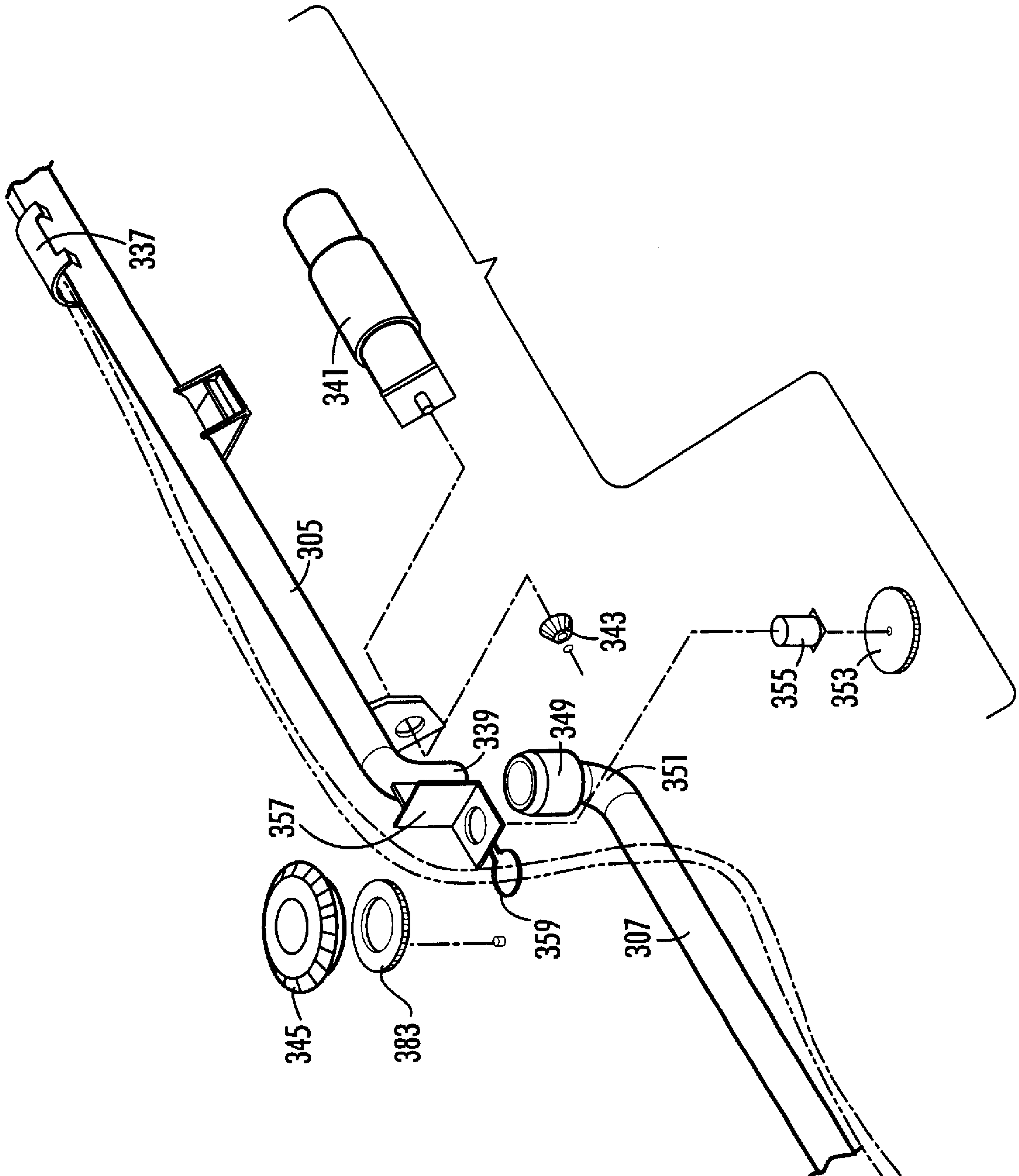


FIG. 9

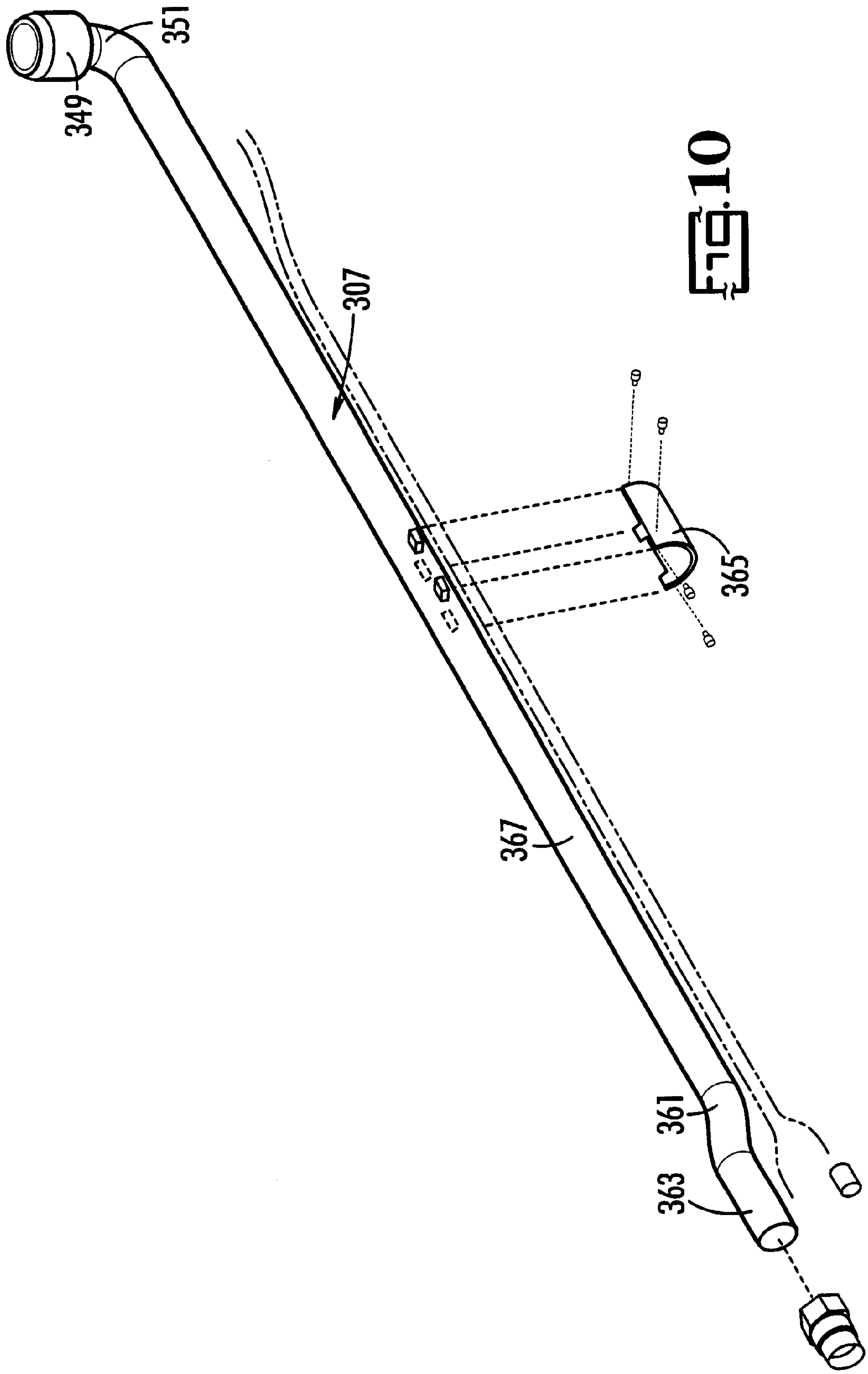


Fig. 10

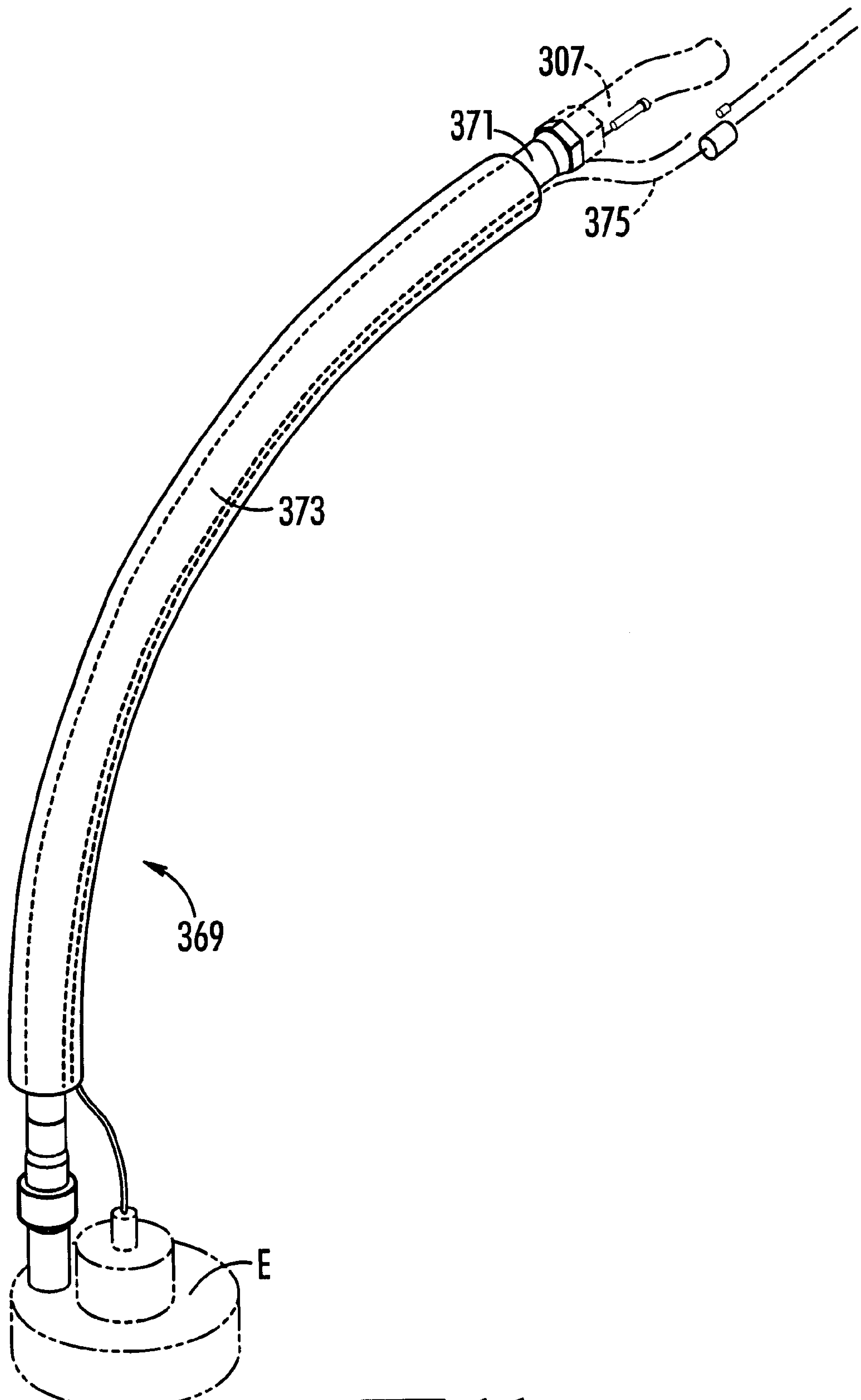


FIG. 11

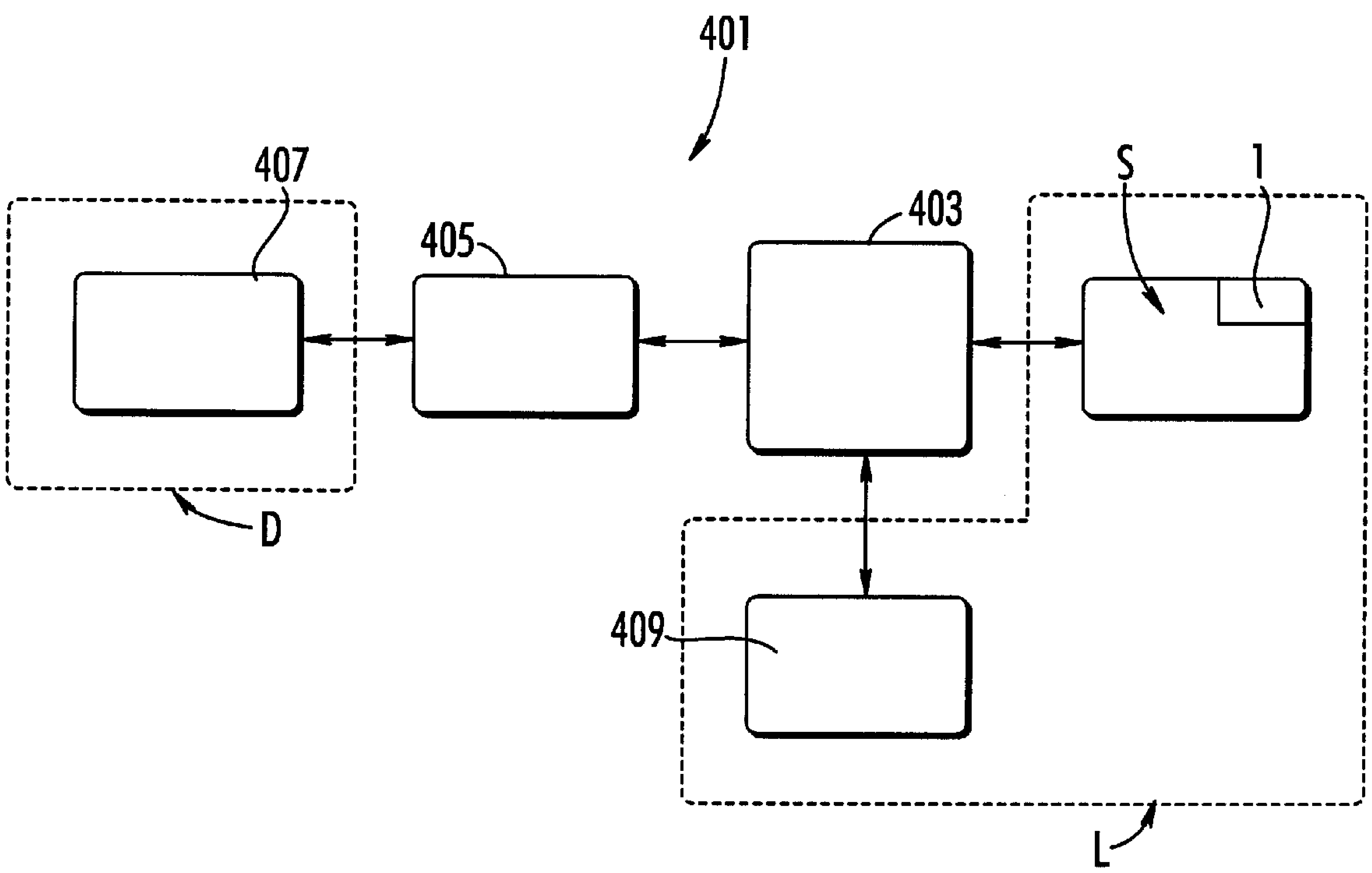


FIG. 12

ROBOTIC SYSTEM FOR RETRACTABLE TELEOPERATED ARM WITHIN ENCLOSED SHELL WITH CAPABILITY OF OPERATING WITHIN A CONFINED SPACE

STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

The U.S. Government has rights in this invention pursuant to contract number DE-AC05-96OR22464 between the Lockheed Martin Energy Research Corporation and the Department of Energy.

BACKGROUND OF THE INVENTION

The present invention relates generally to an apparatus with a teleoperated arm. Specifically, the present invention relates to an apparatus having a teleoperated arm that can perform a variety of tasks in a confined space.

Many difficulties arise when performing tasks within a confined space. For instance, several apparatuses and processes must be simultaneously controlled. In addition, the tool used to perform must be small enough to enter through access ports of limited size. The tool must also reach all necessary locations within the confined space. Despite their limited size, the tools are still required to perform the desired task properly.

When hazardous materials are present in the confined space, the difficulty of performing the task multiplies. Human intervention at the location of the hazardous material or within a confined space is obviously not recommended, or may be prohibited in certain circumstances. In these instances, robotic or teleoperated systems must be used.

Several attempts have been made to provide robotic or teleoperated systems that perform various tasks in confined and/or hazardous spaces. U.S. Pat. No. 4,351,478 to Looper discloses an apparatus for cleaning tanks. The apparatus includes a vertical member that enters the tank. The vertical member supports a wash nozzle assembly. An air motor drives two gear boxes to pivot the wash nozzle in two directions within the tank.

Also, U.S. Pat. No. 5,265,667 to Lester, II et al. discloses a robotic arm for servicing nuclear steam generators. The robotic arm includes a support beam securable to the manway of a steam generator. The support beam allows placement of an extension arm to a suitable position relative to heat exchanger tube in the steam generator in order to allow eddy current inspection of the tubes.

While certainly beneficial in their specific applications, previous attempts at a solution may not be suitable in other confined space situations. In addition, the previous attempts do not integrate the various apparatuses and processes involved in performing a task in a confined space. Clearly, there is room for improvement in the art.

SUMMARY OF THE INVENTION

Therefore, it is an object of the present invention to provide an improved apparatus with a teleoperated arm.

It is a further object of the present invention to provide an apparatus with a teleoperated arm used to perform a variety of tasks in a confined space.

It is a further object of the present invention to provide an apparatus with a teleoperated arm integrated with the processes involved in performing a variety of tasks in a confined space.

It is a further object of the present invention to provide an apparatus with a teleoperated arm that can perform a variety of task within a storage tank by accessing the storage tank through a single riser.

It is a further object of the present invention to provide an apparatus with a four degree of freedom teleoperated arm.

It is a further object of the present invention to provide a teleoperated arm assembly in which the conduits used to transport material for performing tasks within the confined space form the structure of the teleoperated arm.

It is a further object of the present invention to provide a control system that integrates the apparatuses with the processes involved in performing a given task in a confined space.

These and other objects are achieved in one aspect of the present invention by an apparatus for performing a task in a confined space having an access port. The apparatus comprises: a confinement box securable to the access port of the confined space; a shell extending from the confinement box; a teleoperated arm movable between a retracted position, in which the teleoperated arm is disposed within the shell, and a deployed position, in which the teleoperated arm extends through the access port and into the confined space to perform the task; and a control system for commanding the teleoperated arm.

These and other objects are achieved in a second aspect of the present invention by the apparatus comprising: a confinement box; an elongated tube connected to an aperture in an upper end of a main compartment of the confinement box; a teleoperated arm; and a control system operatively connected to the confinement box and teleoperated arm for manipulating the apparatus. The confinement box includes: an aperture at an upper end and an aperture at a lower end securable to the access port of the confined space; a height adjustable table including: a motor for raising and lower the table; a rotatable flange; and a motor for rotating the flange. The teleoperated arm includes: a mast movable within the tube and the confinement box; an inner arm comprising a conduit; a shoulder joint connecting the mast and inner arm, the inner arm being in fluid communication with at least one conduit; a means for actuating the shoulder joint; an outer arm comprising a conduit; an elbow joint connecting the outer arm and inner arm, the outer arm being in fluid communication with the inner arm; and a means for actuating the elbow joint. The mast secures to the rotatable flange and has at least one conduit extending therethrough.

These and other objects are achieved in a third aspect of the present invention by a teleoperated arm assembly, comprising: a first section; a means for translating the first section; a means for rotating the first section; a second section; a shoulder joint connecting the first and second sections; a means for actuating the shoulder joint; a third section; an elbow joint connecting the second and third sections; a means for actuating the elbow joint; and a control system commanding the first section translating means, first section rotating means, shoulder joint actuating means and elbow joint actuating means.

These and other objects are achieved in a fourth aspect of the present invention by a teleoperated arm assembly in which the arm links serve as process conduits integral to the teleoperated arm for the purpose of transporting extractable material from a confined space and/or for the purpose of supplying a process stream or electrical utility to the confined space.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention will become apparent to those skilled in the art to which the present invention relates from reading the following specification with reference to the accompanying in which:

FIG. **1** is a perspective view of the apparatus of the present invention performing a task within an underground storage tank;

FIG. **2** is a perspective view of the containment box assembly of the present invention;

FIG. **3** is a perspective view of the X-Y positioning table of the containment box assembly shown in FIG. **2**;

FIG. **4** is a perspective view of the mast elevate table of the containment box assembly shown in FIG. **2**;

FIG. **5** is a perspective view of the mast rotate assembly of the containment box assembly shown in FIG. **2**;

FIG. **6** is an exploded perspective view of the tube assembly of the present invention;

FIG. **7** is an exploded perspective view of the mast portion of the teleoperated arm assembly of the present invention;

FIG. **8** is a perspective view of the shoulder joint between the mast and the inner arm of the teleoperated arm assembly of the present invention;

FIG. **9** is a perspective view of the elbow joint between the inner arm and the outer arm of the teleoperated arm assembly of the present invention;

FIG. **10** is a perspective view of the outer arm of the teleoperated arm assembly of the present invention;

FIG. **11** is a perspective view of an additional conduit section and an end effect or connectable to the outer of the teleoperated arm assembly of the present invention;

FIG. **12** is a schematic of the control system of the apparatus of the present invention;

DETAILED DESCRIPTION OF THE REFERRED EMBODIMENTS

FIGS. **1**–**12** demonstrate one preferred embodiment of the apparatus of the present invention. Apparatus **1** is part of an overall system S that performs a task within a confined space. In the preferred embodiment, apparatus **1** performs a task within an underground storage tank T. Tank T may require system S, including apparatus **1**, to perform one or more processes within tank T. The processes can include, for example, waste dislodging, scarification, sludge retrieval and sluicing.

As with most underground storage tanks, tank T includes walls W, floor F, dome C and at least one riser R. Risers R provide the only access ports to the interior of underground storage tank T. In a fifty (50) foot diameter tank, the riser may only be two (2) feet in diameter. Apparatus **1** is designed to enter tank T through riser R.

As stated above, apparatus **1** is part of an overall system S that performs tasks within tank T. Aside from apparatus **1**, system S can include, for example, pipes (not shown), hoses (not shown), cables (not shown) and valves (not shown) that supply the necessary materials and/or utilities to apparatus **1** and, possibly, to other apparatuses in system S to perform a task in tank T, and to remove the byproducts that may have been created during performance of the task in tank T.

Apparatus **1** includes several interrelated components, including a confinement box assembly **101**, tube assembly **201**, teleoperated arm assembly **301**, and control system **401**. Apparatus **1**, using control system **401**, integrates confinement box assembly **101**, tube assembly **201**, and especially teleoperated arm assembly **301** with the processes of system S. Each of the components of apparatus **1** will now be individually described in greater detail below.

Confinement Box Assembly

FIGS. **2**–**5** demonstrate a preferred embodiment of confinement box assembly **101**. Confinement box assembly **101** is an enclosure formed of frame members **103** and body panels **105**. An interface pipe connector **107** extends from the bottom portion of confinement box assembly **101**. Confinement box assembly **101** secures to riser R (or a decontamination spray ring (not shown)) by mating a flange **109** on pipe **107** to riser R (or the decontamination spray ring).

Similarly, a pipe **111** extends from the upper portion of confinement box assembly **101**. A flange **113** on pipe **111** mates with a flange **205** on tube assembly **201** described in more detail below. Once secured to riser R and once tube assembly **201** mates with flange **113**, apparatus **1** is a sealed system with tank T. In other words, confinement box assembly **101** and tube assembly **201** enclose the hazardous environment within tank T. If needed, a blind flange (not shown) can mount to flange **113** to cap pipe **111**. The blind flange seals the hazardous environment within tank T and confinement box assembly **101** when tube assembly **201** is not secured to confinement box assembly **101**. To install tube assembly **201** to flange **113**, the blind flange is simply removed from flange **113**.

An X-Y positioning table **117** secures to the bottom of confinement box assembly **101**. X-Y positioning table **117** is used to precisely center mast **303** over riser R. X-Y positioning table **117** rests on existing steel beams (shown in phantom in FIG. **1**) positioned around riser R to seat confinement box assembly **101** over tank T.

As seen in FIG. **3**, X-Y positioning table **117** includes lower frame members **119** which rest upon the steel beams around riser R. Upper frame members **121** are movably positioned on lower frame members **119**. Manually driven ball screw units **123** translate upper frame members **121** in two orthogonal directions relative to lower frame members **119**. Upper frame members **121** secure to the bottom of confinement box assembly **101**. This allows the precise positioning of mast **303** with the center of riser R.

Confinement box assembly **101** has three compartments. Main compartment **115** occupies the middle of confinement box assembly **101** and extends between pipe **107** on the lower portion and pipe **111** on the upper portion. Main compartment **115** has an opening **149** housing a transparent panel **151** (see FIG. **1**). Transparent panel **151** includes glove porting **153** to allow an operator to perform tasks within confinement box assembly **101**. For instance, the operator would use glove portion to secure the conduits from a jumper panel (not shown) in confinement box assembly **101** to fittings **315** on a circular plate **309** of mast **303**.

Main compartment **115** allows passage of a mast **303** of teleoperated arm assembly **301**. When in a retracted position, teleoperated arm assembly **301** preferably resides entirely within tube assembly. When in an extended position, a portion of teleoperated arm assembly **301** preferably resides within confinement box and a portion within tank T.

A mast elevate table **155** resides within main compartment **115** and can raise or lower mast **303** during operations within tank T. Table **155** includes a rectangular plate **129**. Circular plate **309** of mast **303** rests on table **155**. Four actuator screws **125** support rectangular plate **129**. Screw actuators **127**, driven by a motor **147**, rotate screws **125**.

Motor **147** can be, for example, a Baldor **1/2** HP, three phase, **1725** rpm actuator drive motor. Rotation of screws **125** in one direction causes rectangular plate **129** and mast

303 to elevate. Rotation of screws 125 in the opposite direction causes rectangular plate 129 and mast 303 to lower.

A mast rotate assembly 131 mounts to mast elevate table 155. Mast rotate assembly 131 secures to rectangular plate 129 and includes an annular plate 133 supported by bearings 135 mounted to rectangular plate 129. Circular plate 309 of mast 303 rests on annular plate 133. A spacer 137 secures to the lower surface of annular plate 133. A gear 139 secures to spacer 137.

A motor 141, having a gear 143, mounts to rectangular plate 129. Gear 143 meshes with gear 139 to allow rotation of annular plate 133. Motor 141 is, preferably, backdriveable. Control system 401 uses motor 141 and resolver 145 to provide servo control of plate 309.

Confinement box assembly 101 when connected to tank T is a sealed environment, isolated from the outside environment to prevent contamination. Accordingly, access to the interior of confinement box assembly 101 must be controlled. Confinement box assembly 101 uses a conventional pass-through compartment 157 having, for example, bag-in/bag-out capability to provide controlled access to the interior of confinement box assembly 101. As an example, the operator can use pass-through compartment 157 to insert a tool into the interior of confinement box assembly 101 for maintenance activities.

Confinement box assembly 101 also includes a conduit interaction compartment 159. All of the hoses and cabling of system S that connect to apparatus 1 must enter the sealed environment through conduit interaction compartment 159. Conduit interaction compartment 159 uses a transparent panel 161 with glove porting to allow the operator to connect the hoses and cabling to one side of a jumper panel (not shown) residing in conduit interaction compartment 159. The other side of jumper panel resides within main compartment 115 and allows connection of the hoses and cabling to their respective fittings 315 on conduits 317 in mast 303.

Conduit interaction compartment 159 preferably has a discharge port 163 separated from the remainder of conduit interaction compartment 159. Discharge port 163 has a flange 165 surrounding a discharge pipe 167. Discharge process piping (not shown) of system S secures to both flange 165 and discharge pipe 167. Discharge process piping receives the contents retrieved from tank T for subsequent treatment and/or disposal in any conventional manner.

Confinement box assembly 101 can include a decontamination wand (not shown) used to spray teleoperated arm assembly 301 when removed from tank T. System S provides the necessary hoses (not shown) and piping (not shown) to operate the decontamination wand.

Tube Assembly

FIG. 6 demonstrates a preferred embodiment of tube assembly 201. Tube assembly 201 includes a cylindrical portion 203 having a flange 205 at a lower end and an enclosure 207 at an upper end. Flange 205 mates with flange 113 of confinement box assembly 101. Bolts, for example, extending through aligned apertures in flanges 205, 113 secure tube assembly 201 and confinement box assembly 101 together.

Enclosure 207 is formed by body panels 209 secured to frame members 211. A conventional hoist 213 secures to frame members 211. Hoist 213 moves teleoperated arm assembly 301 from a retracted position to a deployed position by attaching to eye bolt 313. Hoist 213 can, for example, have a three thousand (3000) pound capacity. In the extended position, a portion of teleoperated arm assembly 301 preferably resides within tank T. In the retracted position, teleoperated arm assembly 301 preferably resides within tube assembly 201.

Tube assembly 201 can have removable panels at any location in order to allow access to a component of apparatus 1 to allow, for example, maintenance or repair of the component. As an example, cylindrical portion 203 includes a removable panel 215. Removable panel 215 allows access to teleoperated arm assembly 301 when in the retracted position.

Teleoperated Arm Assembly

FIGS. 7–11 demonstrate a preferred embodiment of teleoperated arm assembly 301. Teleoperated arm assembly 301 has several sections, including a mast 303, an inner arm 305, and an outer arm 307. Although teleoperated arm assembly 301 can be designed to satisfy the needs of a particular application, preferably teleoperated arm assembly 301 has four (4) degrees of freedom to allow proper operation of system S within tank T. Preferably, two of the joints are backdriveable, while the others are non-backdriveable.

Mast 303 has an elongated shell portion which includes a half pipe section 379 and a flat plate 381 extending between opposite ends of half pipe section 379. In other words, the elongated shell portion has a D-shaped cross-section. A circular plate 309 encloses the upper end of the elongated shell portion.

Circular plate 309 is the interface point between teleoperated arm assembly 301 and confinement box assembly 101. Two pins 311 extend from the lower surface of circular plate 309. Pins 311 correspond to apertures (not shown) on annular ring 133 of confinement box assembly 101. When pins 311 seat within the apertures, teleoperated arm assembly is properly positioned on mast elevate table 155 of confinement box assembly 101.

Circular plate 309 is also the interface point between teleoperated arm assembly 301 and tube assembly 201. Circular plate 309 has an eye bolt 313 fastened thereto. Eye bolt 313 receives a hook (not shown) or other fastener located at the end of a cable (not shown) extending from hoist 213 of tube assembly 201. Actuation of hoist 213 can either raise teleoperated arm assembly 301 to its retracted position or lower teleoperated arm assembly 301 to its deployed position. Teleoperated arm assembly 301 is in a retracted position when hoist 213 has raised teleoperated arm assembly 301 out of tank T. Teleoperated arm assembly 301 is in a deployed position when teleoperated arm assembly 301 seats on mast elevate table 155 of confinement box assembly 101 and extends into tank T.

Circular plate 309 also includes fittings 315 which allows connection between conduits 317 in mast 303 and the conduits (not shown) from the jumper panel. Conduits 317 can be, for example, pipes (e.g. high pressure water supply lines or suction lines), hoses or electrical cabling (e.g. control cables for the teleoperated arm actuator motors or the instrumentation). Fittings 315, therefore, are appropriate to the specific type of conduit 317.

A conventional hoist assembly 327 attaches to circular plate 309. Hoist assembly 327, using a cable (not shown) connected to inner arm 305 of teleoperated arm assembly 301, pitches inner arm 305 relative to mast 303 (the joint between inner arm 305 and mast 303 can also be referred to as a shoulder). Preferably, hoist assembly 327 pitches inner arm 305 to a perpendicular orientation relative to mast 303. By using hoist assembly 327, shoulder pitch is non-backdriveable. As a precaution, hoist assembly 327 can include a brake (not shown) to fix the position of inner arm **305** relative to mast **303**.

A D-shaped plate **319** encloses the lower end of the elongated shell portion. D-shaped plate **319** is the interface point between mast **303** and inner arm **305**. A resolver **321** mounts to the bottom surface of D-shaped plate **319**. Resolver **321**, along with attached gear **323**, interact with a gear **325** mounted to inner arm **305**. Resolver **321**, along with the other resolvers of apparatus **1**, could be, for example, a Neotech series **2510** resolver with a 0.250" diameter shaft. Control system **401** uses resolver **321** to determine the position, or pitch, of inner arm **305** relative to mast **303** using conventional techniques.

The appropriate transmission ratio for each resolver depends on the gear ratios external to the resolver. As an example, mast rotate resolver **145** could have a 10:1 transmission ratio, shoulder resolver **321** could have a 1.5:1 transmission ratio, and elbow resolver **355** could have a 1:1 transmission ratio.

Inner arm **305** comprises various pipe sections and a pipe swivel, all preferably made of steel. Specifically, inner arm **305** includes an elbow **329**, having a flange **377**, that mates with the lower surface of D-shaped plate **319**. Elbow **329** can be secured to D-shaped plate **319** using, for example, bolts (not shown). Elbow **329** connects to at least one of conduits **317** within mast **303**. In the preferred embodiment, elbow **329** connects a suction line within mast **303**. The external hoses or cabling connects to the remaining conduits **317** in mast **303**.

Inner arm **305** also has a second elbow **331**. To allow shoulder pivot, inner arm **305** uses a conventional rotatable pipe coupling **347** connecting elbows **329, 331**. Pipe coupling **347** along with elbows **329, 331** form the shoulder joint. Rotatable pipe coupling **347** allows the pivotal movement of the shoulder joint. A gear **325** secures to the outer surface of pipe coupling **347**. As discussed above, gear **325** interacts with resolver gear **323** to provide feedback to control system **401**. All of the pipe sections and pipe swivels described herein, including pipe coupling **347** and elbows **329, 331** connect using known techniques.

Inner arm **305** also includes an elongated pipe **333**. One end of elongated pipe **333** rigidly secures to second elbow **331**. As clearly shown in FIGS. **8-10**, discharge port **163** and teleoperated arm assembly **301** (including additional conduit section **369**) serve as the primary conduit of system S for the retrieval and transport of tank contents (e.g. liquids, slurries and/or solids) during operations within tank T.

Pipe **333** has several attachments thereon. An eye **335** secures to the exterior surface of pipe **333**. Eye **335** is the connection point for the cable (not shown) extending from hoist assembly **327** used for shoulder pitch. As hoist assembly unwinds the cable, inner arm **305** rotates from a retracted position parallel to mast **303** to an extended position, preferably perpendicular to mast **303**.

Shielding **317** also secures to pipe **333**. Shielding **337** allows any of the external hoses or cabling required to perform a task within tank T to pass between shielding **337** and pipe **333**. Shielding **337** manages the hoses or cabling so as not to interfere with the joints of the teleoperated arm assembly **301** and protects the hoses or cabling when teleoperated arm assembly **301** is stowed.

A yaw drive motor **341** also secures to pipe **333**. Motor **341** includes a bevel gear **343** which interacts with a bevel gear **345** on outer arm **307**. Motor **341** rotates outer arm **307** relative to inner arm **305**.

Inner arm **305** also includes a third elbow **339** rigidly secured to the distal end of pipe **333**. Third elbow **339**, along with the below-described coupling **349** and fourth elbow **351** form the elbow joint of teleoperated arm assembly **301**. To allow elbow yaw, the elbow joint has a second conventional rotatable pipe coupling **349** secured to the distal end of third elbow **339**. A fourth elbow **351** secures to the distal end of coupling **349**.

Pipe coupling **349** has a bevel gear **345** and a gear **383** secured to an outer surface. Bevel gear **345** interacts with bevel gear **343** on motor **341**. Motor **341** rotates fourth elbow **351** relative to third elbow **339**. Motor **341** is preferably backdriveable.

Gear **383** interacts with a gear **353** connected to a resolver **355**. Resolver **355** mounts to third elbow **339** using a bracket **357**. Control system **401** determines the relative positions, or amount of yaw, between outer arm **307** and inner arm **305** using resolver **355**. Similar to the function of shielding **337**, bracket **357** also includes a guard **359** through which the external hoses or cabling travels. Guard **359** protects the external hoses or cabling from the elbow joint and the exposed gears, and also protects the hoses and cabling when teleoperated arm assembly **301** is stowed.

Outer arm **307** also comprises various pipe sections and a pipe swivel. Outer arm **307** rigidly secures to the distal end of fourth elbow **351**. Outer arm **307** is formed by an elongated pipe **367**. The distal end of pipe **367** has a bent portion **361**. Bent portion **361** orients an end effect or E toward the center of riser R to ensure clearance between teleoperated arm assembly **301** and riser R during deployment into, and retraction from, tank T. An outlet **363** extends from bent portion **361**.

Shielding **365** secures to the outer surface of pipe **367**. Shielding **365** protects any external hoses or cabling required to perform a task within tank T by passing the hoses or cabling between shielding **365** and pipe **367**. Shielding **337** prevents interference between the hoses or cabling with the joints of the teleoperated arm assembly **301** and protects the external hoses or cabling while teleoperated arm assembly **301** is stowed.

Particular tasks within tank T may require teleoperated arm assembly **301** to use an additional conduit section **369**. Section **369** includes an additional pipe section **371**, preferably a flexible, yet rigid, suction hose. A sheath **373** surrounds pipe **371** and a hose bundle **375** required to operate an end effector E.

With the particular end effector E shown in FIG. **11**, hose bundle **375** could include a high pressure water supply, a compressed air supply, motor power cables and feedback cables. End effector E directs the high pressure water at a location in tank T to perform a specific task, such as slurifying. Movement of end effector E within tank T may be accomplished by a different apparatus of system S inserted into tank T through a different riser R. The specific end effector E used with the present invention is not relevant. Any end effector E that can perform a task within tank T could be used by the present invention.

Pipe **371** suctions the slurry. The slurry travels through teleoperated arm assembly **301** and arrives within confinement box assembly **101** for discharge from port **163** and into the discharge process piping (not shown) of system S. Apparatus **1** can accommodate specific types of end effector to perform a task within tank T.

System S can use a jet pump **387** to suction the slurry from end effector E and to propel the slurry through suction line **385** and into the discharge process piping connected to port **163**. To route the slurry into the discharge process piping, suction line **385** connects to discharge pipe **167** in confinement box assembly **101** and to conduits **333**, **367**, **371** of inner arm **305**, outer arm **307** and additional conduit section **369**, respectively.

Jet pump **387** uses no moving parts. A high pressure water line **389** connects to jet pump **387**. Jet pump **387** directs the water from line **389** through nozzles, or jets (not shown), in the interior of jet pump **387**. The jets propel the water upwardly through line **385** towards port **163**. The venturi effect caused by the upward movement of the water creates a suction within the portion of conduit **385** located upstream of jet pump **387** and within conduits **333**, **367**, **371**. The suction draws the slurry towards jet pump **387**. Once the slurry reaches jet pump **387**, the velocity of the water exiting the jets propels the slurry through the remainder of line **385** and towards port **163**. Control system **401** can control jet pump **387**, as with any of the other components of system S.

Although a jet pump has been described herein, the present invention can be used with different types of known pumps, or, if suction is not required to achieve a task within tank T, without a pump entirely.

System S can also include a pressure relief element, such as, for example, a conventional rupture disc assembly **391** connected to suction line **385**. When system S reaches a predetermined dangerous pressure within line **385**, rupture disc assembly **391** fractures. Once ruptured, assembly **391** reroutes the slurry through return line **393**. This prevents possible contamination of the outside environment caused by a dangerous pressure at port **163**. Return line **393** retains the slurry within the sealed environment, preferably dispensing the slurry back into tank T.

Control System

FIG. **12** demonstrates a preferred embodiment of control system **401**. Preferably, the operator conducts operations at a distant location D, remote from the site of tank T. This prevents exposure of the operator to hazardous conditions during operations of system S, including apparatus **1**, in tank T. When desired, however, the operator can conduct operations at a local location L near tank T.

As seen in FIG. **12**, apparatus **1** is part of an overall system S used in performing a task in tank T. System S includes, for example, the pipes (not shown), hoses (not shown), cables (not shown) and valves (not shown) to supply the necessary materials and utilities to apparatus **1** and, possibly, other apparatuses in order to perform a task in tank T, and to remove the byproducts that may have been created during performance of the task in tank T.

Preferably, the operator remotely controls system S, including the teleoperation of arm assembly **301**, in non-real time using a computer system **407** remote from the site of tank T. Computer system **407** can be a microcomputer, such as a Sun workstation utilizing two monitors. One monitor preferably displays the status of teleoperated am assembly **301**, while the other displays the processes of system S. Computer system **407** preferably utilizes a graphical user interface (GUI) to communicate with and to receive commands from the operator.

Computer system **407** interacts with software control logic **405** through a network communication protocol, such as Real Time Innovation's (RTI's) Network Data Delivery System (NDDS). Software control logic **405** performs real-time servo control of teleoperated arm assembly **301** and non-real-time control of the processes of system S via the hardware interface and control logic **403**. In other words, software control logic **405** can selectively signal mast rotate motor **141**, mast elevate motor **147**, shoulder hoist **327** and elbow yaw motor **341** to position teleoperated arm assembly at a desired position within tank T and simultaneously signal process control actuators and valves of system S, including those with apparatus **1**, to control process variables in accomplishing a given task within tank T.

Software control logic **405** uses, for example, a Motorola MVME-**162** CPU and a VME Microsystems International Corporation (VMIC) VMIVME **5787**, Pentium-based PC. The MVMB-**162** runs applications developed using RTI's ControlShell® and run in the ControlShell® environment under Wind River System's VxWorks® real-time operating system. The VMIVME **5787** applications were developed and run using Microsoft's Visual C++ and VMIC's IOWorks® under a Windows NT® operating system. The computers communicate via shared memory and reside together with all of their associated memory devices and I/O boards in the same VME rack.

Software control logic **405** interacts with hardware control logic **403** which provides field connections (not shown) from the computer I/O to the various system hardware. Hardware control logic **403** includes conventional interlocks (not shown) which enable the operator to operate safely from the local control panels **409**.

Local control panels **409** allow an operator to manage system S, including apparatus **1**, at local location L. Preferably, local control panels **409** use manual controls, such as valves (not shown) and electrical control pendants (not shown). Local control panels **409** allow the operator to control system S, including apparatus **1**, in the event of a computer failure. Preferably, each control panel is used to perform a specific operation within system S. For example, one control panel **409** can operate hoist assembly **327**, another can control the process pumps, another can control the arm joints, while yet another controls mast elevate table **155**.

Control system **401** includes a switch (not shown) to transfer control of system S between remote computer **407** and local control panel **409**. Even when the switch has transferred control of system S to a different location, each operator station (ie. remote computer **407** and local control panel **409**) can monitor system S. Each operator station also includes a kill switch (not shown) to shut down system S in an orderly fashion. The kill switches operate at each control panel irrespective of the position of the control transfer switch. In other words, an operator at local control panel **409** can shut down system S even remote computer **407** has control of system S.

Control system **401** integrates the management of apparatus **1**, especially teleoperated arm assembly **301**, with the management of the processes of system S into a single operator station. For example, an operator at remote computer **407** can position teleoperated arm assembly **301** within tank T and can initiate the process steps (such as actuating valves and operating pumps) required to perform a given task within tank T. Control system **401** receives the operators commands from remote computer **407** and directs either apparatus **1** and/or system S using software control logic **405** and hardware control logic **403**.

The assembly and operation of apparatus **1** will now be described. Preferably, apparatus **1** begins as unassembled components. First, confinement box assembly **101** must be secured to riser R of tank T, or to a decontamination ring (not shown) connected to riser R of tank T. Preferably, lower frame members **119** rest on the steel beams (shown in phantom in FIG. **1**).

Since confinement box assembly **101** is large and difficult to precisely position on the steel beams around riser R, the operator manually operates X-Y positioning table **117** to position confinement box assembly **101** directly over riser R. Specifically, the operator aligns pipes **107**, **111** with the center of riser R.

Tube assembly **201**, with teleoperated arm assembly **301** stored therein in its retracted position, is then secured to the top of confinement box assembly **101**. Specifically, flange **205** mates with flange **113**. Apparatus **1** is now properly secured to tank T to prevent migration of the hazardous environment outside of tank T.

Locally, teleoperated arm assembly **301** is deployed to its operational readiness position and is secured to mast elevate table **155**. Specifically, flange **309** mates with flange **129** of confinement box assembly **101**.

Using glove porting **153**, **161**, the operator then connects the outside piping/hoses and cabling (not shown) to the piping/hoses and cabling within apparatus **1** through conduit interaction compartment **159**. The operator connects the conduits from the jumper (not shown) to couplings **315** on circular plate **309**. Apparatus **1** is now ready to perform a given task within tank T.

The operator, preferably located at distant location D, monitors and/or controls the processes involved in the operation of system S, and the operations of apparatus **1**, using the GUI of computer system **407**. If needed, the operator can manually command system S at local location L using control panel **409**. The specific sequence of the process steps used with system S can either be controlled using software, or can be controlled by the operator.

To begin operations within tank T, the operator maneuvers teleoperated arm assembly **301** from its retracted position to its deployed position partially within tank T. In order to perform tasks on outer walls W of tank T, the operator must unfold teleoperated arm assembly **301** by pitching the shoulder joint and yawing the elbow joint.

To initiate the process steps, the operator sends commands to control system **401** by remote computer **407**. For example, the operator may direct control system **401** to open certain valves and to operate certain pumps to achieve a desired result in tank T.

Upon completing the tasks in tank T, the operator sends additional commands to control system **401**. For example, control system **401** can turn off certain pumps and can close certain valves. To remove apparatus **1** from tank T, the operator directs control system **401** to fold teleoperated arm assembly **301** and to partially retract teleoperated arm assembly **301** from tank T.

The operator disconnects all hose and cabling jumper connectors within confinement box assembly **101**. Locally, teleoperated arm assembly **301** is fully retracted into tube assembly **201** using hoist assembly **213** by connecting the hoist cable hook (not shown) to eye bolt **313**. Once removed from tank T, the operator can decontaminate teleoperated arm assembly **301** using a spray wand (not shown) located in confinement box assembly **101**.

Apparatus **1** is disassembled in the reverse order of the assembly process. Disassembly can begin, for example, once the operator performs suitable decontamination protocols and ensures that no hazardous materials will escape into the environment.

Applicants understand that many other variations are apparent to one of ordinary skill in the art from a reading of the above specification. Such variations are within the spirit and scope of the instant invention as defined by the following appended claims.

We claim:

1. An apparatus for performing a task in a confined space having an access port, said apparatus comprising:

a confinement box securable to the access port of the confined space and having a height adjustable table therein;

a shell extending from said confinement box;

a teleoperated arm movable between a retracted position, in which said teleoperated arm is disposed within said shell, and a deployed position in which said teleoperated arm extends through the access port and into the confined space to perform the task, and wherein said teleoperated arm secures to said height adjustable table in the deployed position in order to translate said teleoperated arm, and

a control system for commanding said teleoperated arm.

2. The apparatus for performing a task in a confined space as recited in claim **1**, wherein said teleoperated arm comprises:

a first section;

a means for translating said first section;

a means for rotating said first section;

a second section;

a shoulder joint connecting said first and second sections;

a means for actuating said shoulder joint;

a third section;

an elbow joint connecting said second and third sections; and

a means for actuating said elbow joint.

3. The apparatus for performing a task in a confined space as recited in claim **2**, wherein said second and third sections comprise conduits.

4. The teleoperated arm assembly as recited in claim **2**, wherein said means for actuating said shoulder joint is a means for pitching said second section relative to said first section.

5. The teleoperated arm assembly as recited in claim **4**, wherein said means for pitching said second section comprises a hoist attached to said first section and operatively connected to said second section.

6. The teleoperated arm assembly as recited in claim **2**, wherein said means for actuating said elbow joint is a means for yawing said third section relative to said second section.

7. The teleoperated arm assembly as recited in claim **2**, wherein at least one of said means for rotating said first section and said means for actuating said elbow joint are backdriveable.

8. The teleoperated arm assembly as recited in claim **2**, wherein at least one of said means for translating said first section and said means for actuating said shoulder joint are non-backdriveable.

9. The apparatus for performing a task in a confined space as recited in claim **1**, wherein said tube includes a hoist to move said teleoperated arm between said retracted position and said deployed position.

10. The apparatus for performing a task in a confined space as recited in claim **1**, wherein said teleoperated arm has four degrees of freedom.

11. An apparatus for performing a task in a confined space having an access port, said apparatus comprising:

a confinement box having:

an aperture at an upper end; and

an aperture at a lower end securable to the access port of the confined space;

a height adjustable table including:

a motor for raising and lower said table;

a rotatable flange, and

a motor for rotating said flange;

an elongated tube connected to said aperture in said upper end of said confinement box;

a teleoperated arm including:

a mast movable within said tube and said confinement box, said mast secured to said rotatable flange and having at least one conduit extending therethrough;

an inner arm comprising a conduit;

a shoulder joint connecting said mast and said inner arm, said inner arm in fluid communication with said at least one conduit;

a means for actuating said shoulder joint;

an outer arm comprising a conduit;

an elbow joint connecting said outer arm and said inner arm, said outer arm in fluid communication with said inner arm; and

a means for actuating said elbow joint; and

a control system operatively connected to said confinement box and said teleoperated arm for commanding the apparatus.

12. The apparatus for performing a task in a confined space as recited in claim **11**, wherein at least one of said flange rotate motor and said means for actuating said elbow joint are backdriveable.

13. The apparatus for performing a task in a confined space as recited in claim **11**, wherein at least one of said table motor and said means for actuating said shoulder joint are non-backdriveable.

14. The apparatus for performing a task in a confined space as recited in claim **11**, wherein said mast includes a pair of conduits extending therethrough, and further comprises a pump connected to said pair of conduits so that said pump provides a positive pressure to one of said pair of conduits and provides a negative pressure to the other of said pair of conduits.

15. An apparatus for performing a task in a confined space having an access port, said apparatus comprising:

a confinement box securable to the access port of the confined space and having a rotatable flange therein;

a shell extending from said confinement box;

a teleoperated arm movable between a retracted position, in which said teleoperated arm is disposed within said shell, and a deployed position in which said teleoperated arm extends through the access port and into the confined space to perform the task, and wherein said teleoperated arm secures to said flange in a deployed position in order to rotate said teleoperated arm, and

a control system for commanding said teleoperated arm.

16. The apparatus for performing a task in a confined space as recited in claim **15** wherein said teleoperated arm comprises:

a first section;

a means for translating said first section;

a means for rotating said first section;

a second section;

a shoulder joint connecting said first and second sections;

a means for actuating said shoulder joint;

a third section;

an elbow joint connecting said second and third sections; and

a means for actuating said elbow join.

17. The apparatus for performing a task in a confined space as recited in claim **16** wherein said second and third sections comprise conduits.

18. The teleoperated arm assembly as recited in claim **16** wherein said means for actuating said shoulder joint is a means for pitching said second section relative to said first section.

19. The teleoperated arm assembly as recited in claim **18** wherein said means for pitching said second section comprises a hoist attached to said first section and operatively connected to said second section.

20. The teleoperated arm assembly as recited in claim **16** wherein said means for actuating said elbow joint is a means for yawing said third section relative to said second section.

21. The teleoperated arm assembly as recited in claim **16**, wherein at least on of said means for rotating said first section and said means for actuating said elbow joint are backdriveable.

22. The teleoperated arm assembly as recited in claim **16** wherein at least one of said means for translating said first section and said means for actuating said shoulder joint are non-backdriveable.

23. The apparatus for performing a task in a confined space as recited in claim **15**, wherein said tube includes a hoist to move said teleoperated arm between said retracted position and said deployed position.

24. The apparatus for performing a task in a confined space as recited in claim **15** wherein said teleoperated arm has four degrees of freedom.

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